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COMPARATIVE STUDY OF DIFFERENT OPTIMIZATION TECHNIQUES FOR SLIDING MODE CONTROLLER FOR UNCERTAIN NONLINEAR MIMO SYSTEM

HINGRAJIYA RIKINKUMAR CHANDULAL, RAJESH L. ZADFIYA & RAMANI VIJAY J

Department of Electrical Engineering, Nirma Institute of Technology, Ahmedabad, Gujarat, India

ABSTRACT

In this paper, the robust control problem of general uncertain multi-input multi-output (MIMO) nonlinear three tank systems is introduced. Three different optimization techniques are discussed to design Sliding Mode Control (SMC) based controller for nonlinear coupled Multi-Input Multi-Output (MIMO) system. These three different optimization techniques are genetic algorithm (GAs), fuzzy neural network (FNN) and adaptive fuzzy control. These techniques were implemented on the three tank system. The adaptive fuzzy basis function is used to approximate an unknown nonlinear function with the help of some adaptive laws, upon which an adaptive fuzzy sliding mode controller is introduced. The main disadvantages of the sliding mode control are high control gain and chattering phenomenon. Mentioned optimization techniques are compared to minimize the high control gain and chattering phenomenon by robust sliding mode controller for uncertain nonlinear MIMO three tank system.

KEYWORDS: Genetic Algorithm (GA), Fuzzy Neural Network (FNN), Robust Controller, Sliding Mode Controller and MIMO Nonlinear System

INTRODUCTION

In control theory, sliding mode control, or SMC, is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal that forces the system to "slide" along a cross-section of the system's normal behavior. The state-feedback control law is not a continuous function of time. Instead, it can switch from one continuous structure to another based on the current position in the state space. Hence, sliding mode control is a variable structure control method. The multiple control structures are designed so that trajectories always move toward an adjacent region with a different control structure, and so the ultimate trajectory will not exist entirely within one control structure.

In the sliding-mode control theory, control dynamics have 2 sequential modes, the first is the reaching mode and the second is the sliding mode. In particular, the Lyapunov sliding condition forces system states to reach a hyper plane and keeps them sliding on this hyper plane. Essentially, a SMC design is composed of 2 phases: hyper plane design and controller design. A hyper plane is first designed via the pole-placement approach as in the state-space control; a controller design is then based on the sliding condition. The stability is guaranteed by the sliding condition (Lyapunov's Stability Criterion Theorem) and by a stable hyper plane (stable designer-chosen pole-placement). In the reaching mode, the control dynamics depend on system parameters; but in the sliding mode they depend on the hyper plane, this is the invariance property of the sliding mode. There are 2 stages in the sliding mode control (SMC) design: the hyper plane design and the controller design [1].

An ideal SMC does not exist; it would imply that the Control commutes at an infinite frequency. In the presence of switching time delays and small time constants in the actuators, the discontinuity of the control action produces a particular dynamic behavior in the vicinity of the surface, which is commonly known as chattering.

The chattering phenomenon is the main disadvantage of these types of controllers and all efforts are concentrated on decreasing this singularity. This chattering effect is minimized by genetic algorithm, fuzzy neural network and adaptive fuzzy control.

Consider a nonlinear dynamical system described by

$$\frac{dx}{dt} = f(X,t) + B(X,t)u(t) \tag{1}$$

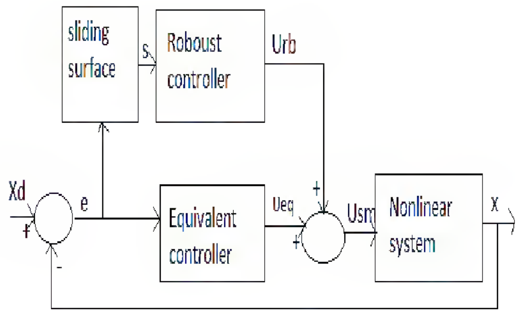

Figure 1: Block Diagram of SMC

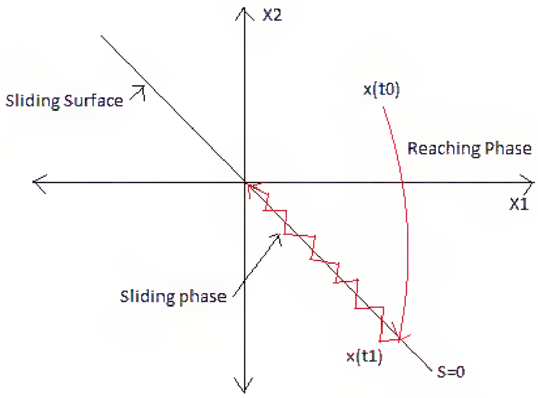

Figure 2: Sliding Mode and Chattering Phenomenon

SLIDING HYPER PLANE AND CONTROLLER DESIGN

In the hyper plane design stage, a sliding hyper plane is computed on the basis of the nominal model. In this paper direct allocation method that may be the simplest way to see what the invariance property really means and is extendable into nonlinear systems. Hyper plane normalization is proposed to greatly simplify a control function in the controller design stage. There are 2 types of eigenvalues to be proposed: sliding-eigenvalue and hyper plane-eigenvalue.

In the controller design associated with this hyper plane, a control function is achieved by satisfying the sliding condition which is in the form of the Lyapunov's direct stability criterion. We can check the stability of the sliding surface using Lyapunov's theorem.

$$V(s) = \frac{1}{2}S.S^T \tag{2}$$

A VSS controller design will be fully developed in a unified manner that is extendable into robust control and MIMO nonlinear systems where a VSS control is a discontinuous sliding mode control (SMC). We propose a stability criterion which is much simpler than the current approach.

APPLICATION OF THREE TANK MIMO SYSTEM

In this paper, an application of nonlinear robust predictive control is developed to a three tanks system shown in figure 3.

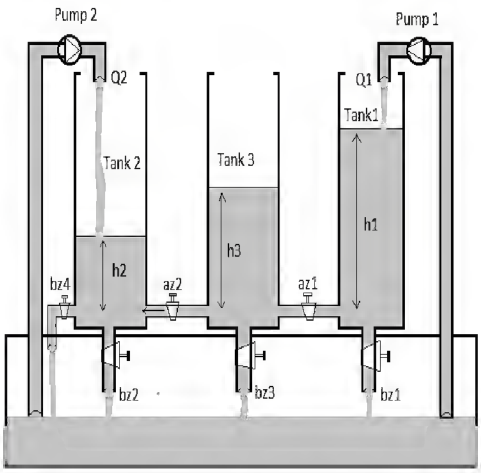

Figure 3: Three Tank System

DESCRIPTION OF THE THREE TANKS MIMO SYSTEM

The considered process is a three tank system, which have two inputs and three outputs. It consist on three cylindrical tanks with identical Section a supplied with distilled water, which are serially interconnected by two cylindrical pipes of identical Sections Sn. The pipes of communication between the tanks T1 and T2 are equipped with manually adjustable valves; the flow rates of the connection pipes can be controlled using ball valves az1 and az2. The plant has one outlet pipe located at the bot-tom of tank T3. There are three other pipes each installed at the bottom of each tank; they are provided with a direct connection (outflow rate) to the reservoir with ball valves bz1, bz2 and bz3, respectively, it can only be manipulated manually. The pumps 1 and 2 are supplied by water from the reservoir with flow rates Q1 (t) and Q2 (t), respectively. The necessary level measurements h1 (t), h2 (t) and h3 (t) are carried out by the piezo-resistive differential pressure sensors.

The water level variations of tanks 1, 2 and 3 depend on the input and output flows and are expressed as follows:

Dynamic equation of three tanks MIMO system are:

$$\frac{dh_1}{dt} = -c_1 sign(h_1 - h_3)\sqrt{|h_1 - h_3|} + \frac{Q_1}{a}$$

$$\frac{dh_2}{dt} = c_3 sign(h_3 - h_2)\sqrt{|h_3 - h_2|} - B_4\sqrt{h_2} + \frac{Q_2}{a}$$

$$\frac{dh_3}{dt} = c_1 sign(h_1 - h_3)\sqrt{|h_1 - h_3|} - c_3 sign(h_3 - h_2)\sqrt{|h_3 - h_2|}$$

Where q1 and q2 are the input flow rates which are controlled by electrical tensions u1 and u2 respectively

SLIDING MODE CONTROLLER USING DIFFERENT CONTROL STRATEGY

- **Sliding Mode Controller Based on Neural Network**

Radial basis function (RBF) neural network is a three layered neurons network consisting of an input layer, a hidden layer and an output layer (shown in Figure 5). The hidden layer uses gauss basis function with its reflection to the output space is non-linear, featured in simple structure and quick convergence speed, fitting any nonlinear functions.

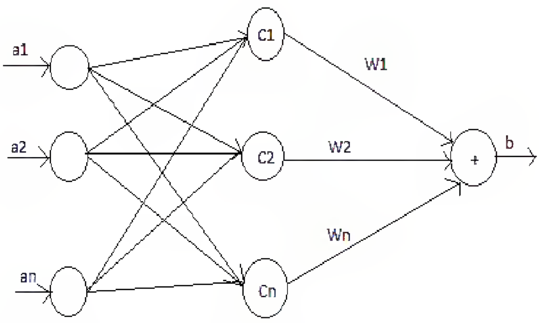

Figure 4: Structure Diagram of RBF Neural Network

In this method here are mainly two methods for optimizing sliding mode control: 1) through the optimization of equivalent controlling force; 2) through the optimization of switch parameters; through neural network optimization of equivalent controlling force employed to optimize sliding mode control effect. A three layer RBF with two inputs and one output is used to fit equivalent controlling force, in which network input is switching surface variable σ and its derivative σ̇, output is equivalent controlling force *f*.

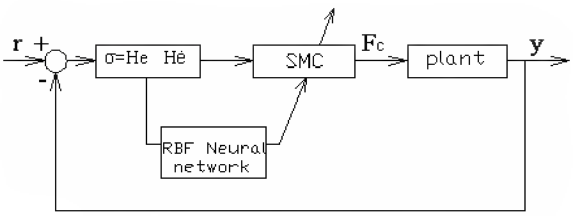

Figure 5: Sliding Mode Control Scheme Based on RBF Neural Network

- **Adaptive Fuzzy Sliding Mode Controller**

In this controller, Fuzzy logic control law can be designed based on some knowledge or without any knowledge about the control system. In addition, an appropriate fuzzy logic controller can overcome the environmental variation during operation processes.

However, the design of a traditional fuzzy controller depends fully on an expert or the experience of an operator to establish the fuzzy rules bank. There is no guide rule for designing the fuzzy rules bank and parameters. A time-consuming adjusting process is required to achieve the specified control performance. Thereafter, self-tuning algorithms were introduced into fuzzy controller to adjust fuzzy parameters and improve the control performance based upon a specified performance index. For controller design need a complicated learning mechanism or a specific performance decision table designed by trial-and-error. Its application still presents certain difficulty. The number of rules increases exponentially with respect to the number of dimensions. In addition, there is still lacking of theoretical modelling and analysis for the fuzzy logic control (FLC) stability and robustness problems.

Hence, the robustness advantage of a sliding mode control was introduced into the fuzzy controller in recent researches. Fuzzy system adjusted by an adaptive law to approximate an optimal controller to a specified accuracy. However, this kind of direct adaptive law is limited to nonlinear system with constant control gain. After that, a fuzzy direct control scheme by using a fuzzy system to approximate an optimal controller that was designed based on the assumption that all of the dynamics in the system were known. Then, a fuzzy sliding controller was added to the adaptive controller for compensating the uncertainties and smoothing the control signal. In sliding mode concept is combined with fuzzy control strategy to design a model-free adaptive fuzzy sliding mode controller for nonlinear systems control.

- **Fuzzy Sliding Mode Controller Based on Genetic Algorithm**

The key to put a genetic search for the FSMC into practice is that all design variables to be optimized are encoded; LS a finite length string. Each design is represented by a binary string. Fitness as a qualitative attribute measures the reproductive efficiency of living creatures according to the principle of survival of the fittest. In the FSMC design, the parameters of controller are determined and optimized through assessing the individual fitness. In order to employ the GA to optimize the FSMC for the system we establish the fitness function according to the objective of active vibration control. Thus the FSMC design based on the GA can be considered as an optimization search procedure over a large parameter space.

The GA control parameters play important role in the procedure of optimizing the parameters of the fuzzy logic controller. Some worthwhile discussions Of the GA parameters are made as follows:

Encoding Form: The linear encoding form is used. The length of binary coding string for each variable is important for the GA. There is always a compromise between complexity and accuracy in the choice of string length. Here, a 16-bit binary coding is used for each parameter.

Crossover and Mutation Rates: Crossover and mutation rates are not fixed during evolution period. At the beginning, crossover and mutation rates are, respectively, fixed to 0.9 and 0.1, then decrease 10 percent in each generation until crossover rate is 0.5 and mutation rate is 0.01.

Population Size: The population size has to be an even number and is kept fixed throughout. Generally, the bigger the population size, the more design features are included. The population size should not k too small, but the procedure of optimizing will be slow when the population size is big.

CONCLUSIONS

Based on literature survey in fuzzy base sliding mode control, fuzzy logic algorithm continuously updates the slope constant of the sliding surfaces of the sliding-mode controller according to the controlled states of the system. Fuzzy sliding mode controller gives smooth chattering in sliding mode control. An Adaptive fuzzy sliding mode controller deal with the parameter uncertainties based on sliding mode control theory and Lyapunov stability theory. This controller has good adaptability and robustness against the parameter variation and external disturbances and reduces the chattering. NN based sliding mode controller gives more effectively performance but it may increase the complexity of the system. In fuzzy sliding mode controller with GA gives optimal parameter and better performance and reduce chattering. Finally conclude that for uncertain nonlinear MIMO system Adaptive fuzzy sliding mode controller gives robustness against uncertainty and external.

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